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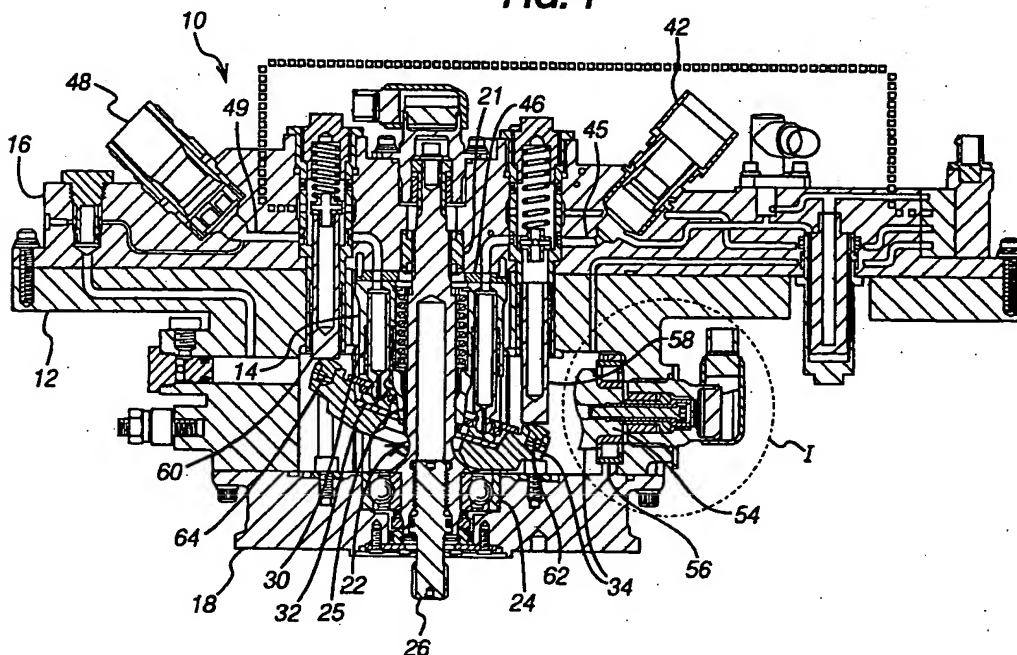
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(54) **Hydraulic motors**

(57) A variable displacement bi-directional hydraulic motor 10 comprising a rotatable member 14 that has an axis of rotation and defines a plurality of cylinder bores, respective pistons 30 received in said bores and a yoke 34 provided with a bearing surface that is engaged by respective bearing members 32 carried at an end of the pistons that projects from the cylinder bores,

said yoke being mounted for pivoting movement about a pivot axis to allow a swash angle of said bearing surface to be varied, whereby the displacement of the motor can be controllably varied and the direction of rotation of the motor can be changed and the arrangement being such that said bearing surface is inclined at a fixed angle in a plane perpendicular to the plane of said swash angle.

**FIG. 1**



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## Description

### Field of the Invention

[0001] The invention relates to variable displacement bi-directional hydraulic motors and particularly, but not exclusively, to such motors for use in aerospace applications.

### Background to the Invention

[0002] Variable displacement bi-directional motors are used for aerospace, marine and defence applications. Typical aerospace applications include actuation of aircraft flap/slat systems. Military vehicle and marine applications include azimuth and elevation servo drives for turret drive systems and missile launchers.

[0003] A variable displacement bi-directional hydraulic motor comprises a plurality of pistons housed in respective bores in a cylinder block. Fluid is sequentially fed into the cylinder block bores to cause the pistons to reciprocate. The pistons each have an end that projects from the cylinder block and is provided with a shoe through which the pistons press against an inclined bearing surface supported by a yoke. The cylinder block is connected with a drive shaft. As the pistons reciprocate within the cylinder block bores, they cause the cylinder block, and so the drive shaft, to rotate. The inclination of the bearing surface can be varied by tilting the yoke so as to vary the displacement. Furthermore, the yoke can be moved over centre so as to change the direction of rotation of the motor, without the need to change the sense of the low and high pressure ports that communicate with the cylinder ports.

[0004] It is an object of the invention to provide improved variable displacement bi-directional hydraulic motors and/or at least provide an alternative to existing designs.

### Summary of the Invention

[0005] The invention provides a variable displacement bi-directional hydraulic motor comprising a rotatable member that has an axis of rotation and defines a plurality of cylinder bores, respective pistons received in said bores and a yoke provided with a bearing surface that is engaged by respective bearing members carried at an end of the pistons that projects from the cylinder bores, said yoke being mounted for pivoting movement about a pivot axis to allow a swash angle of said bearing surface to be varied, whereby the displacement of the motor can be controllably varied and the direction of rotation of the motor can be changed and the arrangement being such that said bearing surface is inclined at a fixed angle in a plane perpendicular to the plane of said swash angle. The inclination of the bearing surface with respect to the plane of the swash angle provides decompression and precompression of the fluid as the cylinder bores

move between the intake and exhaust phases, which may reduce hydraulic pulsations created as the bores are exposed to inlet and exhaust pressure.

[0006] The invention also includes a variable displacement bi-directional hydraulic motor comprising a body rotatable about an axis of rotation and defining a plurality of cylinder bores, respective pistons housed in said cylinder bores for reciprocating movement therein and each having an end projecting from the body, respective bearing shoes provided on said ends of the pistons and a bearing surface disposed opposite said body and engaged by said bearing shoes, said bearing surface being mounted for selective tilting movement about an axis extending perpendicular to said axis of rotation such that a ramp angle of said bearing surface can be selectively varied for varying the displacement and the direction of rotation of the motor and said bearing surface being canted at a fixed angle about an axis extending substantially perpendicular to said tilt axis and said axis of rotation. The canting of the bearing surface provides decompression and precompression of the fluid as the cylinder bores move between the intake and exhaust phases, which may reduce hydraulic pulsations created as the bores are exposed to inlet and exhaust pressure.

[0007] The invention also includes a variable displacement bi-directional motor in which each of a plurality of pistons carried in a body rotatable about an axis of rotation has an end projecting from the body and is provided with a bearing member that engages a bearing surface that is (i) inclined in a first direction with respect to said body to define a ramp for said bearing members, the angle at which said bearing surface is inclined in said first direction being controllably variable to permit the displacement and direction of the motor to be varied, and (ii) inclined in a second direction with respect to said body, which second direction is substantially perpendicular to said first direction. The amount of inclination in the first direction defines the yoke, or swash, angle. The amount of inclination in the second direction defines a cant angle. The cant angle is selected to provide for decompression and precompression of the fluid when the cylinder bores are moving between the intake and exhaust phases, which may reduce hydraulic pulsations created as the bores are exposed to inlet and exhaust pressure.

[0008] The invention also includes a variable displacement bi-directional hydraulic motor, said motor comprising:

- a motor shaft rotatably mounted in a housing and having an axis of rotation;
- a drum fixed on said motor shaft, said drum defining a plurality of bores extending parallel to said housing and having a first opening at a first end thereof and a second opening at a second end thereof;
- a dedicated supply passage for supplying hydraulic fluid and a dedicated exhaust passage for exhaust-

ing hydraulic fluid, said passages being arranged to sequentially communicate with said first openings of said bores when, in use, said motor shaft rotates, whereby hydraulic fluid is supplied to and exhausted from said bores;

respective pistons housed in said bores and each having a leading end projecting from the second opening of the respective bore;

respective bearing members fixed on said leading ends of said pistons so as to be movable relative thereto;

a part defining a bearing surface engaged by said bearing members, said part being pivotally supported in said housing so as to be pivotable about a pivot axis extending perpendicular to the axis of rotation such that, in use, said bearing surface can be controllably pivoted about said pivot axis to provide a variable angle ramp having a ramp angle and said bearing surface being inclined at a fixed angle about an axis that is perpendicular to said pivot axis and said axis of rotation; and

a mechanism to allow a control system to act on said part defining a bearing surface to cause pivoting movement thereof such that said ramp angle is varied to control the displacement and direction of rotation of the motor. The fixed angle of inclination of the bearing surface provides decompression and precompression of the fluid as the cylinder bores move between the intake and exhaust phases, which may reduce hydraulic pulsations created as the bores are exposed to inlet and exhaust pressure.

[0009] The invention also includes a variable displacement bi-directional hydraulic motor having a plurality of hydraulically actuated axially displaceable pistons arranged to react against a bearing surface to generate a torque for rotating a motor shaft, said bearing surface being inclined at a fixed angle in a first direction with respect to the respective axes of said pistons and at a variable angle in a second direction substantially perpendicular to said first direction, wherein, in use, variation of said variable angle controls the displacement and direction of rotation of said motor. The inclination of the bearing surface in the first direction defines a fixed cant angle. The selection of the cant angle provides decompression and precompression of the fluid as the cylinder bores move between the intake and exhaust phases, which may reduce hydraulic pulsations created as the bores are exposed to inlet and exhaust pressure.

[0010] The invention also includes a hydraulic control system in an aircraft provided with a variable displacement bi-directional hydraulic motor as specified in any one of the last preceding five paragraphs.

#### Brief Description of the Drawings

[0011] In order that the invention may be well under-

stood, an embodiment thereof, which is given by way of example only, will now be described, with reference to the drawings, in which:

Figure 1 is a sectional view of a variable displacement bi-directional hydraulic motor;

Figure 2 is a perspective view of a cylinder block and piston sub-assembly of the hydraulic motor of Figure 1;

Figure 3 is a scrap section showing a part of the yoke and piston/shoe assembly of the motor of Figure 1;

Figure 4 is a schematic view of a valve port arrangement for feeding the cylinder block shown in Figure 2;

Figure 5 is an enlarged scrap cross-section of the yoke of Figure 3; and

Figure 6 is a schematic representation of the bearing surface of the yoke.

#### Detailed Description of a Preferred Embodiment

[0012] Figure 1 is a cross-sectional view of a variable displacement bi-directional hydraulic motor 10. It is to be noted that the segment of the drawing marked I is rotated 90° with respect to the remainder of the drawing.

[0013] The variable displacement bi-directional hydraulic motor 10 (hereinafter "over centre motor") comprises a motor casing 12 that has a hollow central portion housing a rotatably mounted cylinder block 14. One end of the motor casing 12 is closed by a valve block, or valve plate, 16 and the other end is closed by a face plate 18.

[0014] The cylinder block 14 has an axially extending throughbore 20. A drive shaft 22 extends through the throughbore 20 and has one end rotatably supported in a radial bearing 21 mounted in the valve block 16 and the other end rotatably supported by a radial-thrust rolling bearing 24 that is mounted in the face plate 18. The drive shaft 22 is coupled to the cylinder block 14 by any suitable means, such as splines 25. A coupling shaft 26 is fixed to the end of the drive shaft that is supported in the face plate 18 and projects beyond the face plate for coupling to a device to be driven by the motor 10. Suitable seals and/or packing are variously provided between the motor casing 12, valve block 16, face plate 18, drive shaft 22 and coupling shaft 26 where required in order to retain hydraulic fluid within the motor 10.

[0015] Referring again to Figure 2, the cylinder block 14 defines a plurality of cylinder bores 28 that extend parallel to the axis of rotation of the cylinder block. The cylinder bores 28 are on a common pitch circle and each houses a hollow piston 30. Each piston 30 is able to re-

reciprocate in its cylinder bore 28 and has an end that projects from the cylinder block. As best seen in Figure 3, the projecting ends of the pistons define a ball which is fitted into a ball socket of a respective piston shoe 32. The piston shoes 32 have planar engagement faces that slidably engage a bearing surface 33 provided on a yoke 34 (Figures 1, 3 and 5).

[0016] Referring to Figure 3, the piston shoes 32 each have a relatively narrow neck 35 that is received in respective apertures 36 provided in a shoe hold down plate 37. Axial retention of the shoe hold down plate 37 is provided by a retainer ring 38 that is secured to the yoke 34 by screws 39. The face of the retainer ring 38 that engages the shoe hold down plate 37 is provided with a bearing surface, which may be in the form of a bronze facing.

[0017] Referring to Figure 2, the rear end of the cylinder block 14 is provided with respective ports 41 for the cylinder bores 28. Hydraulic fluid passes into and out of the cylinder bores via the cylinder block ports 41 to provide reciprocating movement of the pistons 30. The supply of hydraulic fluid to and from the cylinder block ports 41 is through the valve block 16. The valve block is provided with an inlet, or high pressure, port 42 for connection with a source of pressurised hydraulic fluid. The inlet port 42 is connected with an arcuate slot 43 (Figure 4) by an inlet passage 45 defined in the valve block. The arcuate, or kidney, slot 43 is defined by a wafer plate 46 (Figure 1), which is positioned between the valve block 16 and the cylinder block 14. The kidney slot 43 may alternatively be defined in the valve block so that a wafer plate 46 is not needed. The provision of a wafer plate permits greater freedom in the selection of valve block material, which allows for cost and weight savings. For example, where a wafer plate is used, the plate can be made of steel allowing the valve block to be made of aluminium.

[0018] The valve block 16 also has an exhaust port 48 and defines an exhaust passage 49 that connects the exhaust port with a second arcuate, kidney, slot 50 defined by the wafer plate 46. The wafer plate 46 is arranged such that as the cylinder block 14 rotates, the cylinder block bores 41 sweep over the kidney slots 43, 50 in such a way that pressurised hydraulic fluid is sequentially admitted to the cylinder block bores 28 via the high pressure kidney slot 43 and then exhausted via the low pressure kidney slot 50. The kidney slots 43, 50 may be symmetrically or asymmetrically positioned about the top and bottom dead centre positions of the cylinder block 14 to provide optimised biased timing. This provides higher efficiency and reduced hydraulic pulsations.

[0019] The yoke 34 is a generally annular member with a generally centrally disposed through-hole, which receives the drive shaft 22. The yoke 34 has oppositely disposed pintles 54, one of which is shown in Figure 1. The pintles 54 are supported by respective pintle bearings 56 (preferably cylindrical rolling bearings) support-

ed in the motor casing 12. As described in more detail below, the mounting of the yoke 34 in the pintle bearings 56 permits pivoting of the yoke about a pivot axis 70 (Figures 5 and 6) defined by the pintles 54 to control the displacement of the motor and its direction of rotation. In the embodiment, the pivot axis is at right angles to the axis of rotation 76 of the cylinder block 14.

[0020] The over centre motor 10 has two control pistons 58, 60 that act on respective buttons 62, 64 provided on the yoke 34. The buttons 62, 64 are positioned symmetrically about the yoke pivot, or tilting, axis 70. Pivoting of the yoke 34 about its pivot axis 70 is controlled by the selective supply and exhaust of hydraulic fluid acting on the control pistons 58, 60.

[0021] Referring to Figures 5 and 6, the bearing surface 33 is a plane surface. In Figure 6, it is represented schematically as a rectangular surface, although it is in fact an annular surface. The pivot mounting of the yoke in the pintle bearings 56 allows the bearing surface to be pivoted about the pivot axis 70. The amount of pivoting is controlled by the control pistons 58, 60. From the neutral position illustrated in Figure 6, if the bearing surface 33 is pivoted in the direction indicated by arrow 72 the drive shaft 22 will rotate in a first direction 74 with respect to the axis of rotation 76 and if the bearing surface is pivoted in the direction indicated by arrow 78, the drive shaft will rotate in a second, opposite direction 80. The amount of pivoting, or degree of inclination, of the bearing surface with respect to the tilt axis 70 determines the swash, or ramp; angle  $\alpha$  of the bearing surface. Varying the swash angle  $\alpha$  varies the displacement of the motor, whereas the direction of inclination with respect to the neutral position determines the direction of the motor.

[0022] In addition to being inclined with respect to the tilt axis by the variable angle  $\alpha$ , the bearing surface 33 is inclined at a fixed cant angle  $\beta$  in a plane perpendicular to the plane of the swash angle  $\alpha$ . Thus, the bearing surface is inclined in two mutually perpendicular directions, the amount and direction of inclination being fixed in one direction and variable in the other. The cant angle  $\beta$  is shown somewhat exaggerated in the drawings for ease of recognition.

[0023] In use, as each piston 30 reaches the region of its top dead centre position (minimum cylinder volume), it is subjected to hydraulic fluid at inlet pressure that is supplied from the inlet passage 45 via the high pressure kidney slot 43 and its cylinder block port 41. The hydraulic fluid drives the piston down its cylinder bore 28. The axial force of the piston is applied through the piston shoe 32 to the bearing surface 33. Due to the "down ramp" effect, the piston exerts a tangential force, which creates a torque acting on the cylinder block 14. The torque is transferred to the drive shaft 22 through the splines 25. The sum of the individual piston torques is the total torque developed by the motor.

[0024] As each piston reaches its bottom dead centre position (maximum cylinder volume), its cylinder block

port 41 opens to the exhaust passage 49 via the low pressure kidney slot 50. The piston shoe 32 now moves "up ramp" and the piston forces the hydraulic fluid in the cylinder bore 28 into the exhaust passage 49. When the piston is back in the region of top dead centre, it is ready for the next power stroke. During the exhaust stroke, the piston shoes 32 are maintained in engagement with the bearing surface by the shoe hold down place 37 and the retainer ring 38.

[0025] The introduction of the cant angle  $\beta$  allows correct precompression of the hydraulic fluid when passing through the top dead centre position. Correct precompression ensures that the volume of fluid contained in the cylinder bore is at a pressure close to that of the supply as it enters the high pressure kidney slot 43. Equalising these pressures before the cylinder bore opens, reduces the pressure pulsation that would otherwise occur. The introduction of the cant angle  $\beta$  allows correct decompression of the hydraulic fluid when passing through the bottom dead centre positions. Correct decompression ensures that the volume of fluid contained in the cylinder bore is at a pressure close to that of the return as it enters the low pressure kidney slot 50. Equalising these pressures before the cylinder bore opens, reduces the pressure pulsations that would otherwise occur.

[0026] By reducing pressure pulsations in the low and high pressure ports 42, 48, both airborne and structure borne noise resulting from operation of the motor are reduced.

[0027] As will be appreciated, the inclination of the bearing surface 33 determined by the ramp angle  $\alpha$  provides for a change of cylinder volume as the pistons move up and down ramp. By providing a second direction of inclination transverse, and preferably perpendicular, to the first direction of inclination, a change of volume of the cylinder bores is provided as the piston passes between the two kidney slots 43, 50. By selecting a suitable cant angle  $\beta$ , the decompression and precompression of the fluid can be optimised to the common operating mode of the motor. The optimum cant angle  $\beta$  will depend on the system pressure, speed of rotation, swash angle and fluid compressibility. It is envisaged that the cant angle  $\beta$  will typically be a fixed angle in the range  $1^\circ$  to  $5^\circ$  and more preferably the angle might be fixed at  $3^\circ$ . Surprisingly, the provision of the cant angle  $\beta$  provides the correct decompression and precompression of the fluid, regardless of the direction of rotation of the motor.

[0028] In the embodiment illustrated by Figure 5, the cant angle  $\beta$  is machined into the yoke 34. However, it will be understood that as an alternative, an annular ring having a wedge-shaped section defining the cant angle could be fitted to the yoke.

[0029] It is envisaged that the over centre motor 10 will be used in aircraft hydraulic systems, where the reduction in the airborne and structure borne noise obtained by the introduction of the cant angle should prove

advantageous.

[0030] The embodiments provide an improved variable displacement bi-directional hydraulic motor, with reduced hydraulic pressure pulsations. Reducing pulsations has a benefit on fatigue life and noise levels. In particular, positioning of the kidney slots with respect to the top and bottom dead centre positions in conjunction with the selection of the cant angle  $\beta$  can provide optimised biased turning together with decompression and precompression of the fluid in the cylinder bores to provide high efficiency and reduced hydraulic pulsations. The inventors have made the surprising discovery that uniquely the cant angle can be incorporated in bi-directional motors by the existence of dedicated high and low pressure ports. It would not be possible where the sense (inlet/exhaust) of the ports changes when changing the sense of rotation.

[0031] The over centre motor 10 may include features of the Vickers® RMV3-160-1 Intelligent Motor™ as set out in Product News PN 640-1 8/99, published in 1999 by the Eaton Corporation, the content of which is incorporated by reference.

## Claims

1. A variable displacement bi-directional hydraulic motor comprising a rotatable member that has an axis of rotation and defines a plurality of cylinder bores, respective pistons received in said bores and a yoke provided with a bearing surface that is engaged by respective bearing members carried at an end of the pistons that projects from the cylinder bores, said yoke being mounted for pivoting movement about a pivot axis to allow a swash angle of said bearing surface to be varied, whereby the displacement of the motor can be controllably varied and the direction of rotation of the motor can be changed and the arrangement being such that said bearing surface is inclined at a fixed angle in a plane perpendicular to the plane of said swash angle.
2. A motor as claimed in claim 1, wherein said fixed angle is substantially in the range  $1^\circ$  to  $5^\circ$ .
3. A motor as claimed in claim 2, wherein said fixed angle is substantially  $3^\circ$ .
4. A motor as claimed in claim 1, 2 or 3, wherein said fixed angle is provided by forming said bearing surface on said yoke.
5. A variable displacement bi-directional hydraulic motor comprising a body rotatable about an axis of rotation and defining a plurality of cylinder bores, respective pistons housed in said cylinder bores for reciprocating movement therein and each having an end projecting from the body, respective bearing

shoes provided on said ends of the pistons and a bearing surface disposed opposite said body and engaged by said bearing shoes, said bearing surface being mounted for selective tilting movement about an axis extending perpendicular to said axis of rotation such that a ramp angle of said bearing surface can be selectively varied for varying the displacement and the direction of rotation of the motor and said bearing surface being canted at a fixed angle about an axis extending substantially perpendicular to said tilt axis and said axis of rotation.

6. A variable displacement bi-directional motor in which each of a plurality of pistons carried in a body rotatable about an axis of rotation has an end projecting from the body and is provided with a bearing member that engages a bearing surface that is (i) inclined in a first direction with respect to said body to define a ramp for said bearing members, the angle at which said bearing surface is inclined in said first direction being controllably variable to permit the displacement and direction of the motor to be varied, and (ii) inclined in a second direction with respect to said body, which second direction is substantially perpendicular to said first direction.

7. A motor as claimed in claim 6, in which the amount of the incline in said second direction is fixed.

8. A variable displacement bi-directional hydraulic motor, said motor comprising:

a motor shaft rotatably mounted in a housing and having an axis of rotation;

a drum fixed on said motor shaft, said drum defining a plurality of bores extending parallel to said housing and having a first opening at a first end thereof and a second opening at a second end thereof;

a dedicated supply passage for supplying hydraulic fluid and a dedicated exhaust passage for exhausting hydraulic fluid, said passages being arranged to sequentially communicate with said first openings of said bores when, in use, said motor shaft rotates, whereby hydraulic fluid is supplied to and exhausted from said bores;

respective pistons housed in said bores and each having a leading end projecting from the second opening of the respective bore;

respective bearing members fixed on said leading ends of said pistons so as to be movable relative thereto;

a part defining a bearing surface engaged by said bearing members, said part being pivotally supported in said housing so as to be pivotable about a pivot axis extending perpendicular to the axis of rotation such that, in use, said bear-

ing surface can be controllably pivotted about said pivot axis to provide a variable angle ramp having a ramp angle and said bearing surface being inclined at a fixed angle about an axis that is perpendicular to said pivot axis and said axis of rotation; and

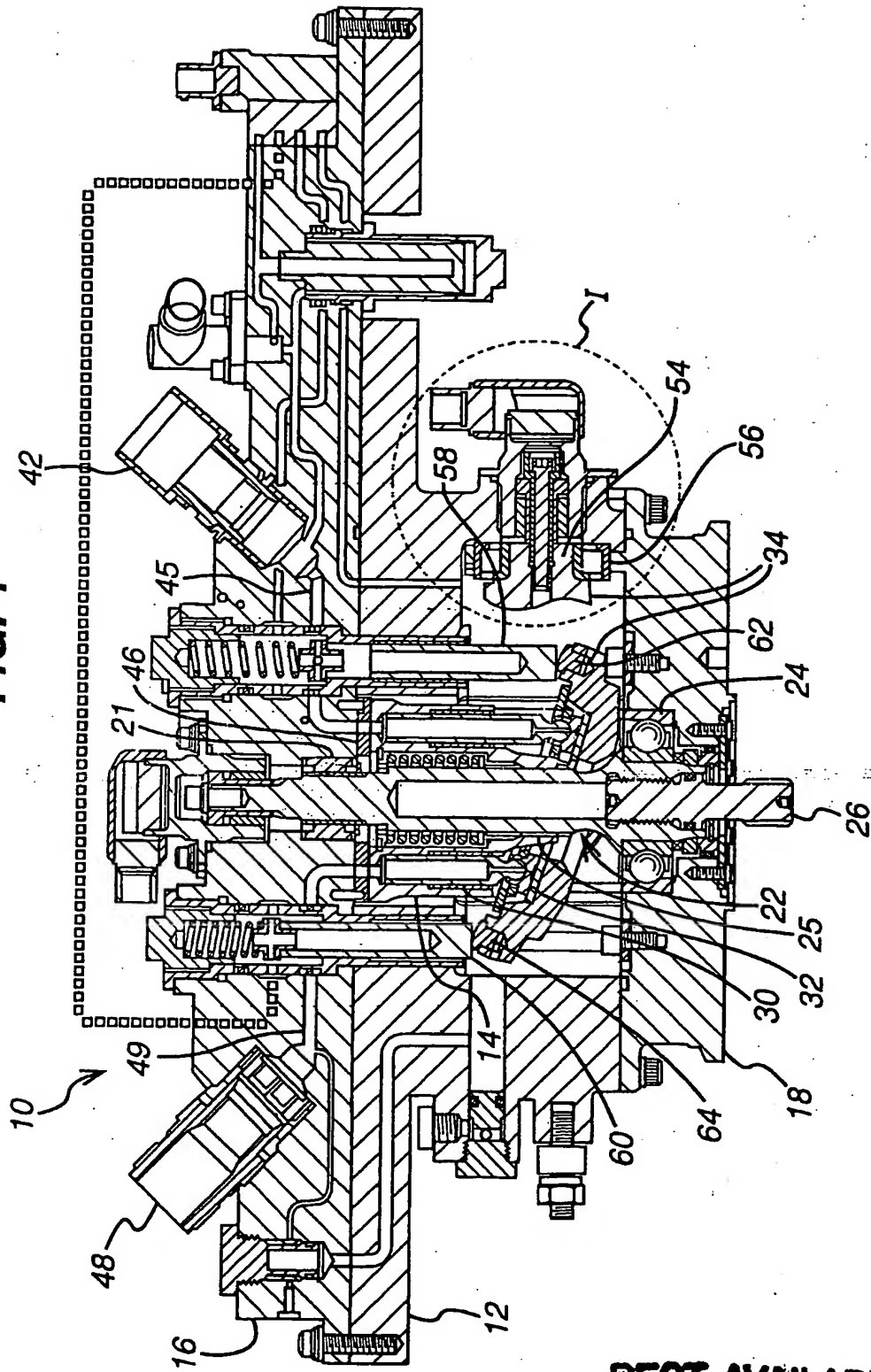
a mechanism to allow a control system to act on said part defining a bearing surface to cause pivoting movement thereof such that said ramp angle is varied to control the displacement and direction of rotation of the motor.

9. A variable displacement bi-directional hydraulic motor having a plurality of hydraulically actuated axially displaceable pistons arranged to react against a bearing surface to generate a torque for rotating a motor shaft, said bearing surface being inclined at a fixed angle in a first direction with respect to the respective axes of said pistons and at a variable angle in a second direction substantially perpendicular to said first direction, wherein, in use, variation of said variable angle controls the displacement and direction of rotation of said motor.

10. A hydraulic control system in an aircraft comprising a variable displacement bi-directional hydraulic motor as claimed in any one of the preceding claims.

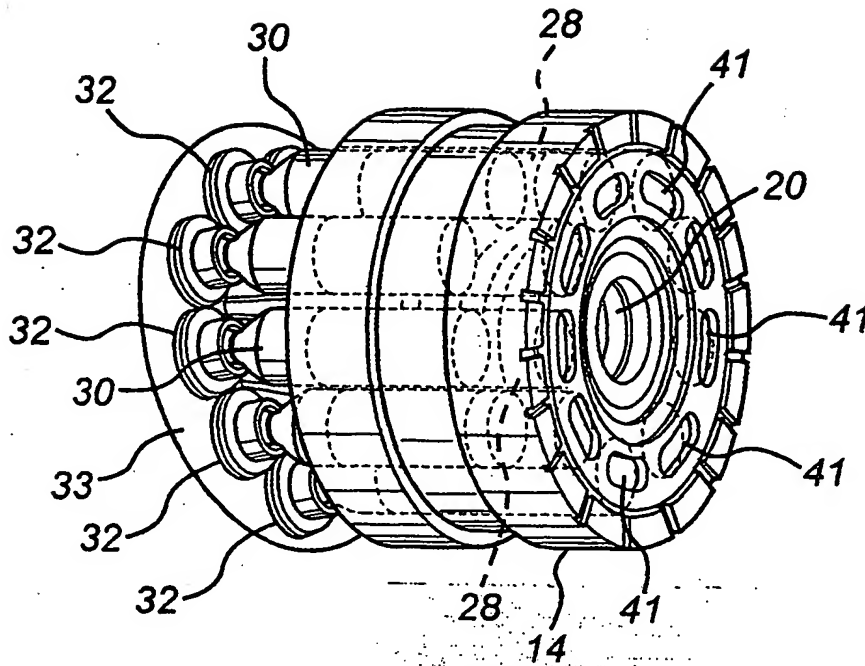
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FIG. 1

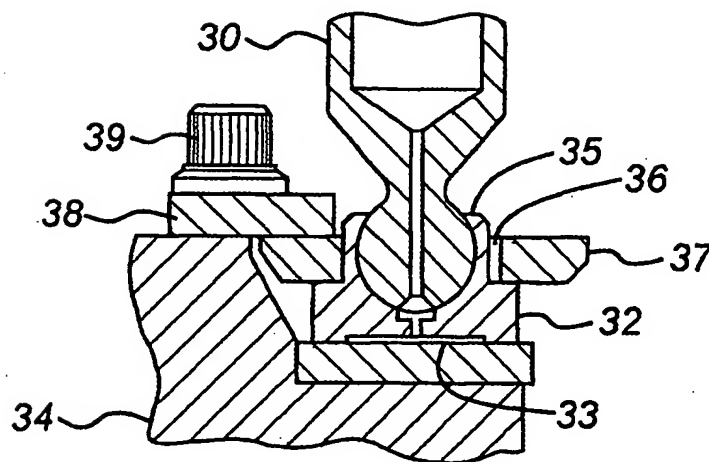


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**FIG. 2**



**FIG. 3**



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